AD-A247 459

242100-1-P

Interim Report

CALIBRATION OF P-3/SAR WAKE DATA

DTIC
S ELECTE
MAR 1 0 1992
D

N. MALINAS

Center for Earth Sciences
Advanced Concepts Division

January 1992

Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217-5000
Scientific Officer : Mr. James A. Fein
Contract No.: N00014-91-C-0266

ERIM P.O. Box 134001
Ann Arbor, MI 48113-4001

92-05672

92 3 03 095

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED

1b RESTRICTIVE MARKINGS

2a SECURITY CLASSIFICATION AUTHORITY

2b DECLASSIFICATION/DOWNGRADING SCHEDULE

3 DISTRIBUTION/AVAILABILITY OF REPORT: UNLIMITED

4 PERFORMING ORGANIZATION REPORT NUMBERS(S): 242100-1-P

5 MONITORING ORGANIZATION REPORT NUMBER(S): N00014-91-C-0266

6a NAME OF PERFORMING ORGANIZATION: Environmental Research Institute of Michigan

6b OFFICE SYMBOL (if applicable)

7a NAME OF MONITORING ORGANIZATION: Office of Naval Research

6c ADDRESS (City, State, and ZIP Code): P.O. BOX 134001, Ann Arbor, MI 48113-4001

7b ADDRESS (City, State, and ZIP Code): 800 N. Quincy Street, Arlington, VA 22217-5000

8a NAME OF FUNDING/SPONSORING ORGANIZATION: Office of Naval Research

8b OFFICE SYMBOL (if applicable)

9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c ADDRESS (City, State, and ZIP Code): 800 N. Quincy Street, Arlington, VA 22217-5000

10 SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO	PROJECT NO	TASK NO	WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification): Interim Progress Report Calibration of P-3/SAR Wake Data

12 PERSONAL AUTHOR(S): N. Malinas

13a TYPE OF REPORT: Interim Report

13b TIME COVERED: FROM 12/91 - 1/92

14 DATE OF REPORT (Year, Month, Day): January 1992

15 PAGE COUNT: 32

16 SUPPLEMENTARY NOTATION

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Calibration constants were generated using trihedral corner reflector data collected by the ERIM/NADC P-3 SAR during the 1989 ONR Ship Wake Experiment. These values will be applied to the ONR data to generate absolutely calibrated radar cross-section (RCS) values for the wake feature and ship and normalized RCS values (σ_o) values for the ambient areas. Results of applying the constants to ambient data from the ONR collection to generate absolutely calibrated σ_o measurements are discussed.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED

22a NAME OF RESPONSIBLE INDIVIDUAL: Norm Malinas

22b TELEPHONE (Include Area Code): (313) 994-1200

22c OFFICE SYMBOL

DD Form 1473, JUN 86 Previous editions are obsolete

ERIM 116

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

An important part of our wake measurement effort is the calculation of the absolute radar cross-section (RCS) of the wake feature itself. To generate an absolute RCS measurement it is first necessary to absolutely calibrate the imaging system. The data used in our wake measurements was collected by the ERIM/NADC P-3/SAR during the 1989 ONR Ship Wake Experiment at the Pacific Missile Test Center (PMTC). A summary of this collection can be found in [1]. Calibration and performance of the P-3/SAR has been documented in the past [2] and will not be discussed here. In this report, the calibration coefficients to be used for absolute calibration of the wake experiment data will be generated from images of corner reflectors deployed on San Nicholas Island during the ONR experiment.

We have generated calibration coefficients for the primary band/polarization configuration employed during the ONR experiment using all currently processed reflector data available from that collection. The algorithm to calculate the calibration constants will be described in Section 2 and the results of applying the algorithm will be presented in Section 3. In Section 4 the results of applying the calibration constants to wake data will be described. An example set of calculations is included as Appendix A. Finally, some conclusions from this work are presented in Section 5.

2.0 TECHNICAL APPROACH

Presented below is the algorithm for calculating the calibration constants which are used to generate absolutely calibrated RCS measurements from processed SAR imagery. First, a brief discussion of the received power of a SAR system due to a point scatterer will be made. A description of the data sets used for this work will be provided and finally the algorithm for generating the calibration constants will be described.

2.1 BACKGROUND

The received power of a SAR system due to a particular scatterer can be described by

$$P_{r_{tot}}(\theta) = \frac{P_t\, G^2(\theta)\lambda^2\sigma(\theta)}{(4\pi)^3 R^4(\theta)} \tag{1}$$

where P_t and $P_{rtot}(\theta)$ are the transmit and total received powers respectively, θ is the incidence angle under consideration, $G(\theta)$ is the one-way antenna gain pattern (assume that the gain is the same for transmit and receive), λ is the system wavelength, $\sigma(\theta)$ is the total cross-section of the scatterer, and $R(\theta)$ is the range to the scatterer. The value of $P_r(\theta)$ is obtained from the imagery (i.e. the image intensity) on a pixel-by-pixel basis where each pixel corresponds to a particular spatial area. The total RCS of a point scatterer in a processed image is calculated by

$$\sigma(\theta) = \Sigma\ \sigma_o(\theta)\Delta a\Delta r \tag{2}$$

where Δa and Δr are the azimuth and range sample spacings respectively and the summation is taken over the spatial area of the scatterer. Therefore, in a digitally processed SAR image, the total RCS of a point scatterer can be calculated from the individual pixel intensities, $P_r(\phi)$, by

$$\sigma(\theta) = \frac{(4\pi)^3 R^2(\theta)}{P_t G^2(\theta)\lambda^2} \Sigma P_r(\theta)\Delta a\Delta r \tag{3}$$

or in other words, the pixel energy value represents a σ_o value; i.e. energy per unit area. Note that the range dependence has been changed to an $R^2(\theta)$ from the $R^4(\theta)$ shown in Eq.(1). An $R^2(\theta)$ factor is removed during the processing of point targets due to an increase in the processing azimuthal aperture with increasing slant range [3,4].

To obtain a value for the absolutely calibrated total RCS, $\sigma_{abs}(\theta)$, we simply scale the received image intensity to obtain

$$\sigma_{abs}(\theta) = K \frac{[\Sigma P_r(\theta)\Delta a\Delta r] R^2(\theta)}{P_t G^2(\theta)} \tag{4}$$

where K is a calibration constant which generates the absolutely calibrated measurement from the data and again the summation is taken over the spatial area covered by the scatterer. The value of K contains the numerical constant and the wavelength dependence seen in Eq.(3).

The value of the calibration constant, K, is dependent upon a variety of factors which are all calculated relative to some arbitrarily chosen set of reference values. In this manner, all images regardless of system geometry or power settings can be calibrated relative to each other. A set of reference parameters have been chosen to calculate the calibration constants for this particular data set. These values are selected as R_o=4000 meters, transmit power = -30 dB, and receiver attenuation = 20 dB. Note that both the receiver attenuation and the transmit power values are included in the value of P_t shown in Eq.(4). These reference values are typical for operation of the P-3 over land areas. The antenna correction for each channel is based upon existing patterns.

With each data set collected, the P-3 records certain system parameters during collection. In particular, a record of the transmitted power level is available as well as the receiver attenuation settings for each channel. Therefore, image measurements can be scaled to some reference power level. The range to scene position is known from the image sample spacing and the recorded near edge slant range of the image thus allowing the selection of a constant range reference. The relative antenna gain is available for each band and polarization configuration. These gain values were obtained from the antenna manufacturer and have since been modified based upon reflector measurements from many different data collections. The measurements provided by the antenna manufacturer were obtained on a test range and differ from the measured elevation patterns due to interference with the airframe once the antenna is mounted. These differences have been documented in previous studies [5,7]. A previous analysis indicated that at C-band VV, the antenna gain is a constant 2.7 dB higher for right look collections relative to left-look collections. The L-band HH pattern has been measured to have differences with respect to look direction as well, with the difference being variable over our range of interest but under 3dB. In applying corrections to the data, the appropriate pattern as a function of look direction will be applied. These patterns are plotted in Appendix B.

2.2 DATA SET

There exist five different processed four channel (X,C,L - VV, and L-HH) sets of imagery along with an additional C-VV image which contain reflectors located on San Nicholas Island. These data sets contain reflectors positioned over an incidence angle range from about 40 to 50 degrees. The run/pass numbers and collection dates of these data sets are provided in Table 1.

Five different sizes of reflectors were deployed along the San Nicholas Island airport runway ranging in size from 18 centimeters to 90 centimeters (measured in length of the perpendicular edges). For much of the wake data collected, the incidence angle of the ships is around 45 degrees thus offering an opportunity to use the reflector data collected at this range of incidence angles to calibrate the wake signatures. It is assumed, however, that the calibration constants derived in this report will be applicable outside the angular region of analysis as well.

2.3 CALCULATION OF THE CALIBRATION CONSTANT

The first step in calculating the calibration constants is to measure the RCS of the deployed triangular corner reflectors. It has been established in a previous effort [2] that the 3dB energy measurement of the corner reflector leads to a more accurate measure of the total RCS than the direct total energy measurement because it is less sensitive to background contributions and focusing. Thus, measurements of the total reflector RCS are made using the pixel energy within the 3dB level and then scaled by the pixel area. If it is assumed that the focussed IPR is a perfect 2-dimensional sinc function, the total RCS of the reflector is 2.6 dB greater than that of the 3dB energy. As a result, the measured 3dB energy of the reflector is increased by 2.6 dB to generate the total RCS of the given reflector. Note that in the processing of the

TABLE 1

Data Sets Used For Calibration of Wake Data

Date	Pass
24 Jan 89	31
25 Jan 89	41
26 Jan 89	30
28 Jan 89	35
29 Jan 89	38
31 Jan 89	34 (C-VV Only)

imagery used for this report, a weighting function is applied to the data to reduce sidelobe contributions in the final processed image. This weighing (a Taylor weighing with sidelobe level -30 dB and N=4) will slightly distort the shape of the processed IPR, however for this analysis the effects are not significant and the 2.6 dB factor will be utilized. This assumption has been validated in previous work [3].

The measured reflector RCS values are adjusted to transform the values to equivalent measurements at a range of 4000 meters, a transmit power of -30 dB and a receiver attenuation of 20 dB. As previously mentioned, these parameters represent a typical operating configuration for the P-3. The antenna elevation pattern weighting is then removed (subtracted in dB). At this point one would like to compare the measured RCS value with the theoretical value expected for a trihedral corner reflector. The theoretical RCS of a trihedral corner reflector is calculated by

$$\sigma = \frac{4\pi l^4}{3\lambda^2} \tag{5}$$

where l is the length of the reflector's mutually perpendicular edges and λ is the imaging wavelength. The values of σ_{max} for the five different reflector sizes deployed are presented in Table 2. These values represent a maximum RCS value assuming that the reflector is being imaged along its axis of symmetry. Generally, this is not the case and so compensation must be made. If it is assumed that the reflector face lies along the azimuth imaging direction, the theoretical RCS of the reflector can be described by [2]

$$\sigma_t = \sigma F(\theta,\phi) \tag{6}$$

TABLE 2

Theoretical Corner Reflector RCS Values

length	X-Band	L-Band	C-Band
.889m	34.06 dB	16.58 dB	29.15 dB
.711	30.16	12.72	25.27
.533	25.16	7.71	20.26
.356	18.16	0.70	13.25
.178	6.12	-11.34	1.21

where

$$F(\theta,\phi)=3[Z(\theta,\phi)-\frac{2}{Z(\theta,\phi)}]^2 \tag{7}$$

with

$$Z(\theta,\phi)=\sin(\theta)\cos(\phi)+\sin(\theta)\sin(\phi)+\cos(\theta) \tag{8}$$

and θ and ϕ are described by Figure 1. As stated in the figure, the maximum RCS of a trihedral corner reflector occurs when $\theta=55$ degrees and $\phi=45$ degrees (the reflector boresight).

For each reflector value measured, the calibration constant is finally calculated as

$$K_i=10LOG_{10}(\sigma_{max})-10LOG_{10}(\frac{E_{3dB}(\theta)R^2(\theta)}{G^2(\theta)R_o^2F(\theta,\phi)})-(P_{atten}-20)+(30+P_{xmit})-2.6 \tag{9}$$

where P_{atten} is the receiver attenuation in dB, and P_{xmit} is the transmit power in dB (negative value) and E_{3dB} is defined by

$$E_{3dB}(\theta)=\Sigma\ [\ P_r(\theta)-B\ ]\Delta a\Delta r \tag{10}$$

where B is the mean background image intensity and the summation is taken over the 3dB resolution widths of the reflector IPR. The background value is estimated over a small region near the reflectors but away from the IPR sidelobes.

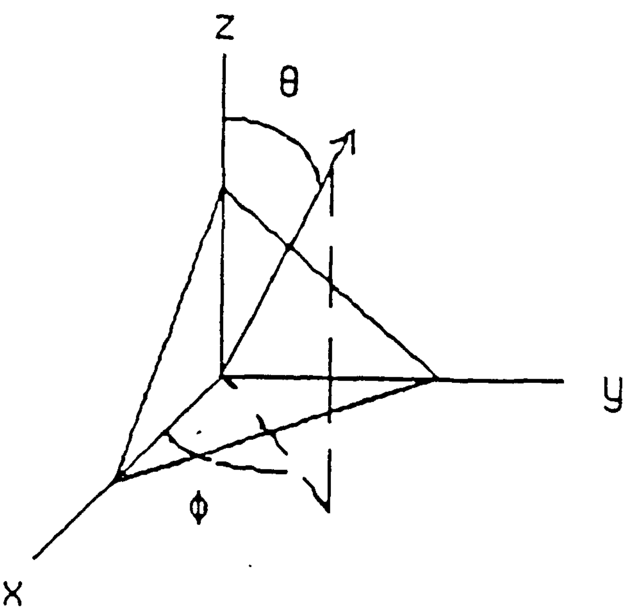


Figure 1. Trihedral Corner Reflector Geometry. Boresight of the Reflector is at $\theta=55°$ and $\phi=45°$.

3.0 RESULTS

After calculations of K for each reflector were made there were indications that the largest reflectors were partially saturated in some of the imagery. Results also showed that in many cases the smallest reflectors (18 cm) were not visible in the imagery. For these reasons, the calibration constant calculated for each channel is based upon measurements of the middle three reflector sizes deployed.

First order statistics combining the calibration constant values obtained for the 71, 53, and 36 centimeter reflectors were calculated over the range of incidence angles for the four different channels collected. These values are presented in Table 3. This table shows that the standard deviation of the calculated calibration constants is about $\pm$ 2.0 dB. This value represents the variability measured in the estimated RCS values for data collected over the incidence angle range spanned by these data sets; i.e. 40-50 degrees incidence angle.

There are several potential sources of error in the calculation of the calibration constants. The recorded receiver attenuation is accurate to $\pm$ 0.5 dB while the transmit power is accurate to $\pm$ 0.05 dB. The errors in measured slant range are negligible and it is not precisely known what the variability of the antenna patterns is for the wakes data set. It is expected, however, that the variability is near $\pm$ 1 dB based upon previous analysis of other data sets [5]. Analysis of corner reflector measurements from other collections [6] gives a stability measure of the measured reflector RCS values to be at or under $\pm$ 1 dB. However, in [6] the reflectors were known to be in the linear operating region of the system for the reflector data. It is possible in this data set that the reflectors used for this analysis are slightly saturated. If this is true, then our measured values of K will be slightly larger. Combining the described sources of error gives a maximum error bar of about $\pm$ 2.5 dB which is

TABLE 3

Calibration Constants for ONR Wake Data
For Ro=4000m, P_{atten}=20 dB, P_{xmit}=-30 dB

Band-Pol	K_{ave} (dB)	σ (dB)
X-VV	-57.98	2.20
L-VV	-70.45	2.24
C-VV	-75.12	1.04
L-HH	-72.13	2.41

consistent with our measurements. RCS values calculated outside the angular range of 40-50 degrees incidence angle may have higher error bars depending upon the accuracy of the antenna elevation patterns. As stated earlier, many of the imaged ships appear near 45 degrees incidence angle so that the antenna pattern accuracy outside the 40-50 degree incidence angle range should not be a significant problem.

The calculated coefficients will be applied to the wake data measurements to calculate the absolute ambient σ_o values, the absolute wake RCS and the absolute ship RCS values as well (neglecting any saturation effects). Throughout this report we have assumed that a point target is being imaged and the calculation of the total RCS of this target is obtained from Eq.(4). We will assume an additive model for the received SAR intensities as

$$r(x,y) = b(x,y) + s(x,y) \tag{11}$$

where r(x,y) is the image intensity at image indices (x,y), b(x,y) is the ambient clutter, and s(x,y) is the response of interest (i.e. wake or ship). Therefore, Eq. (4) is applicable for the RCS measurements of these features. The ocean surface is a distributed target, however, and must be treated in a different manner. We have defined the range reference above as the slant-range. The ground range of an image pixel is defined as $x' = x/\sin(\theta)$ where x is the pixel slant-range. Because we are no longer measuring a point target, we must compensate for the total ground area of the image pixel by introducing the $\sin(\theta)$ term. Note that in measuring a σ_o value we do not sum the contributions of some target to calculate a total RCS value, but instead we form an average of the pixel intensities in a clutter area to arrive at a mean σ_o value which is then normalized by the ground range pixel factor to give

$$\sigma_{o_{-}}(\theta) = 10LOG_{10}\left[\frac{R^2(\theta)\sin(\theta)\left[\frac{1}{N}\Sigma\, (P_r(\theta) - B\,)\right]}{R_o^2 G^2(\theta)} \right] + K + (P_{atten} - 20) - (30 + P_{xmit}) \tag{12}$$

where $\sigma_{oabs}(\theta)$ is the absolutely calibrated σ_o value of the clutter and B in this case is the mean additive system noise value which is estimated from the pre-nadir intensity of the image. For these data sets the pre-nadir energy values are small relative to the scene energies thus we can ignore any scaling of the additive noise due to the processing azimuthal aperture as a function of range.

4.0 APPLICATION OF CONSTANTS TO ONR DATA

Eq.(12) was applied to ambient data collected during the wakes experiment to calculate σ_{oabs} values. A first measurement was taken from a water area contained within the reflector images. These measurements are shown in Table 4 where the incidence angle corresponding to the measurement is 42 degrees. The wind speed for this pass was approximately 10-15 knots.

Tables 5 and 6 contain measurements of ambient σ_o values for two different passes collected hours apart on the same day. Both these passes have high recorded wind speeds (approximately 15-20 knots) and are actual wake collections. The ambient areas used for measurement were taken well away from the wake features and the ship. Looking at the table, we see that the C- and X-band measurements are quite similar. Processed L-band data was not readily available for Run 7-4.

Table 7 contains absolutely calibrated $\sigma_o$measurements from Run 5-4 collected January 28, 1989. This data represents a low wind speed condition with the recorded values being about 9 knots. This table shows that the X- and C-band measurements are more than 6 dB lower than the high wind speed case, however, the L-band measurement is slightly larger.

TABLE 4

Absolute σ_o Values Measured From Data Collected
29 Jan 89, Pass 38

Band-Pol	σ_o
X-VV	-16.51 dB
L-VV	-17.04
C-VV	-18.63

TABLE 5

Absolute σ_o Values Measured From Data Collected
23 Jan 89, Run 7-4

Band-Pol	σ_o
X-VV	-17.47 dB
C-VV	-18.81

TABLE 6

Absolute σ_o Values Measured From Data Collected
23 Jan 89, Run 6-3

Band-Pol	σ_o
X-VV	-17.38 dB
L-VV	-21.56
C-VV	-19.25

TABLE 7

Absolute σ_o Values Measured From Data Collected
28 Jan 89, Run 5-4

Band-Pol	σ_o
X-VV	-25.55 dB
L-VV	-19.13
C-VV	-24.53

5.0 CONCLUSIONS

This report provides the algorithm used to calculate calibration coefficients to be applied to the ONR Wakes data set to generate absolutely calibrated wake measurements. The calibration constants provided have measured standard deviations of about 2 dB within the incidence angle range of 40-50 degrees. The majority of the wake data collected has the ship located in this incidence angle range thus allowing a direct comparison between the reflector data and the ship/wake feature. The calibration constants have been applied to various data sets and ambient σ_o values were calculated. The expected wind speed dependence (lower σ_o with lower wind speed) was observed between two data sets collected at relatively high and low wind speeds. The provided calibration constants may be biased due to possible saturation effects in the reflector images. These calibration constants will be applied to various images to generate absolutely calibrated wake total RCS and the ship total RCS as well as the corresponding ambient σ_o values. The results of these measurements will be provided in a future report.

6.0 REFERENCES

[1] Lyden, J.D., "Ship Wake Experiment - Phase II, SAR Data Summary", ERIM Technical Memo # RR-89-059, February, 1989

[2] Sheen, D.R., Kasischke, E.S., "Overview of Data Collection Flights For System Characterization and Calibration", ERIM Technical Report, September, 1989.

[3] Sheen, D.R., Sullivan, R.A., "Sar Image Calibration", ERIM Technical Memo # RR-89-135, March, 1989.

[4] Freeman, A. et al., "Shuttle Imaging Radar - C Calibration Workshop Report", Jet Propulsion Lab, Pasadena, CA., Technical Report 88-003, November, 1988.

[5] Malinas, N.P. et al.,"Initial Analysis of Antenna Patterns", ERIM Technical Report, September, 1989.

[6] Kasischke, E.S., Gineris, D.G., "Analysis of System Linearity and Stability", ERIM Technical Report, September, 1989.

[7] Cichon, D.J. et al., "Estimation of the P-3/SAR L-, C-, and X-band Antenna Directivity in Range Direction Based on Corner Reflector Measurements Within the Absolute Sar Calibration", IGARSS Symposium, pp. 993-996, June 1991.

APPENDIX A

In this appendix we will walk through the calculation of both an absolutely calibrated σ_o value for an ambient clutter area and also the total RCS of a trihedral corner reflector as calculated for this report.

To calculate the absolute σ_o value we first obtain a mean intensity measurement from a selected clutter area which is located at a particular geometry. Assume for this example that we have generated a mean intensity value of 15160 for X-band data at a range of 4222 meters corresponding to an incidence angle of 41 degrees. For this example the pre-nadir mean intensity was measured to be 500. Thus, our uncalibrated value of σ_o is $10*LOG_{10}(15160-500)=41.66$ dB. We now apply the various corrections.

The range reference is $R_o=4000$ meters so the range correction is $10LOG_{10}((4222/4000)^2) = 0.47$ dB.

The two-way antenna pattern weighing at this incidence angle is measured to be -15.90 dB at X-band; thus the correction is +15.90 dB.

The receiver attenuation for this pass was recorded to be 2 dB so the correction is (2-20) = -18 dB.

The recorded transmit power value was recorded to be -32.4 dB thus the correction for this is (30-(-32.4)) = 2.4 dB

The incidence angle of 41 degrees leads to a pixel area correction of $10*LOG_{10}(\sin(41)) = -1.83$ dB.

Lastly, we apply the calibration coefficient derived in the report which is K=-57.98 dB.

Thus we have

$$\sigma_o(41) = 41.66 + .47 + 15.90 - 18.0 + 2.4 - 1.83 - 57.98 = \mathbf{-17.38\ dB}$$

which is the result presented in Table 6 for Run 6-4 X-Band on 1/23/89.

We will now walk through the calculation of the absolutely calibrated RCS for an imaged corner reflector. Note that for a point target, we are interested in the total RCS of the reflector, σ_{tot}, not the energy per unit area, σ_o.

To calculate the absolute total RCS of a trihedral corner reflector we first obtain the 3dB energy of the reflector as described by Eq.(10) by summing the pixel intensities (with a mean background value intensity subtracted from each sample) over the 3dB extent of the reflector IPR. As an example let's assume that the measured 3dB energy of a 71 cm reflector in a C-Band image is 76.87 dB. Assume that this reflector exists at a range of 3960m corresponding to an incidence angle of 44.2 degrees. To calibrate this response we will simply solve for σ_{max} in dB in Eq.(9). We now apply the various corrections.

The total reflector RCS is 2.6 dB larger than that of the measured E_{3dB} value, thus we add 2.6 dB to the measurement.

The range reference is R_o=4000 meters so the range correction is $10LOG_{10}((3960/4000)\hat{}2) = -0.09$ dB.

The two-way antenna pattern weighing at this incidence angle is measured to be -7.72 dB at C-band; thus the correction is +7.72 dB.

The receiver attenuation for this pass was recorded to be 23 dB so the correction is (23-20) = 3 dB.

The recorded transmit power value was recorded to be -39.5 dB thus the correction for this is (30-(-39.5)) = 9.5 dB.

The correction for reflector incidence angle is calculated using Eq.(7,8) with θ=44.2 degrees and ϕ=45 degrees as $10*LOG_{10}(0.837)$ = -0.77 dB thus the correction factor is + 0.77 dB.

Lastly, we apply the calibration coefficient derived in the report which is K=-75.12 dB.

Thus we have

σ_{abs} = 76.87 + 2.6 - 0.09 + 7.72 + 3 + 9.5 + 0.77 - 75.12 = **25.25 dB**

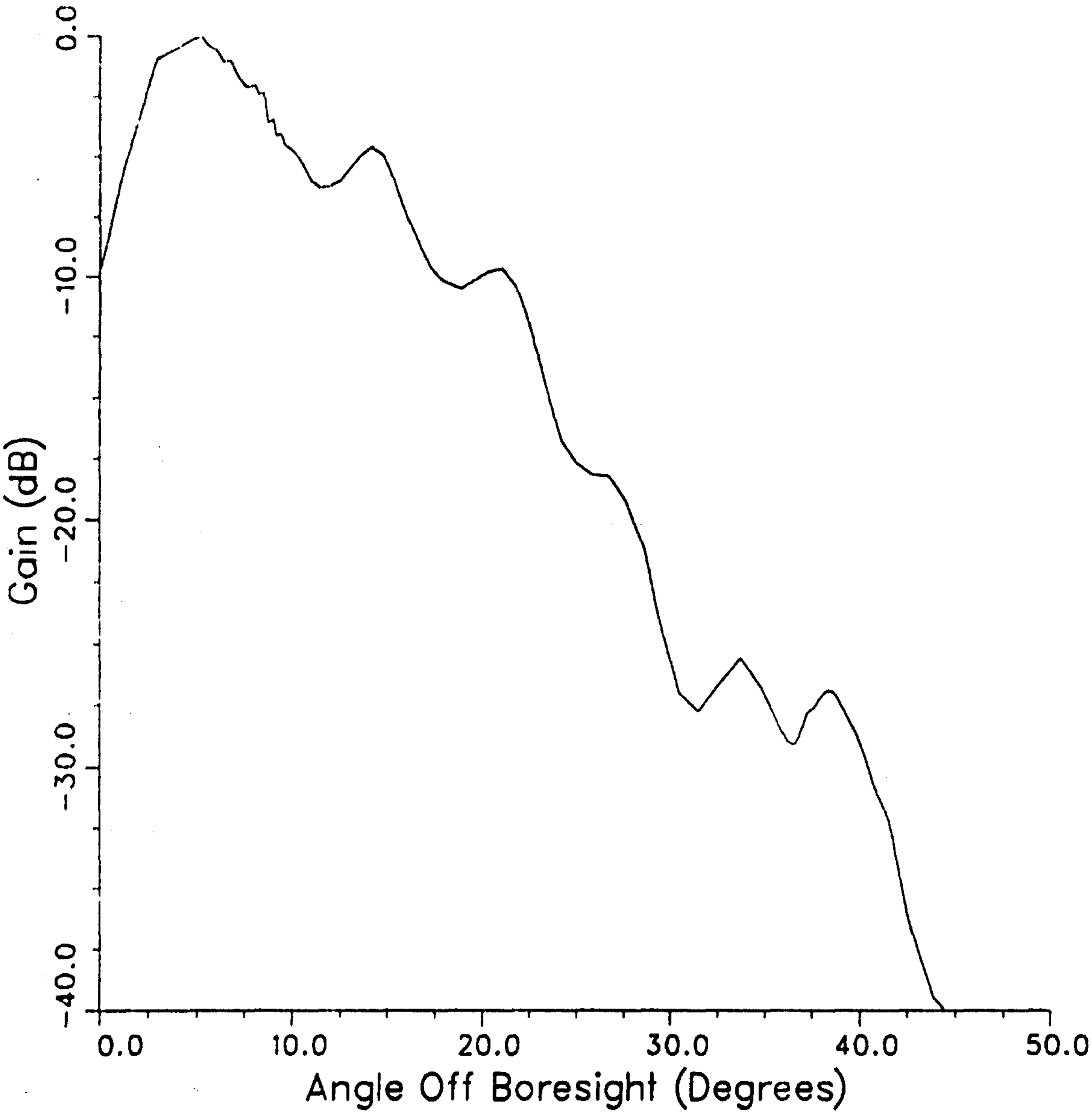
which is very close to the theoretical value of 25.27 dB for this particular reflector.

APPENDIX B

This Appendix contains plots of the antenna elevation patterns for the band/polarization configuration used during the ONR wakes collection.

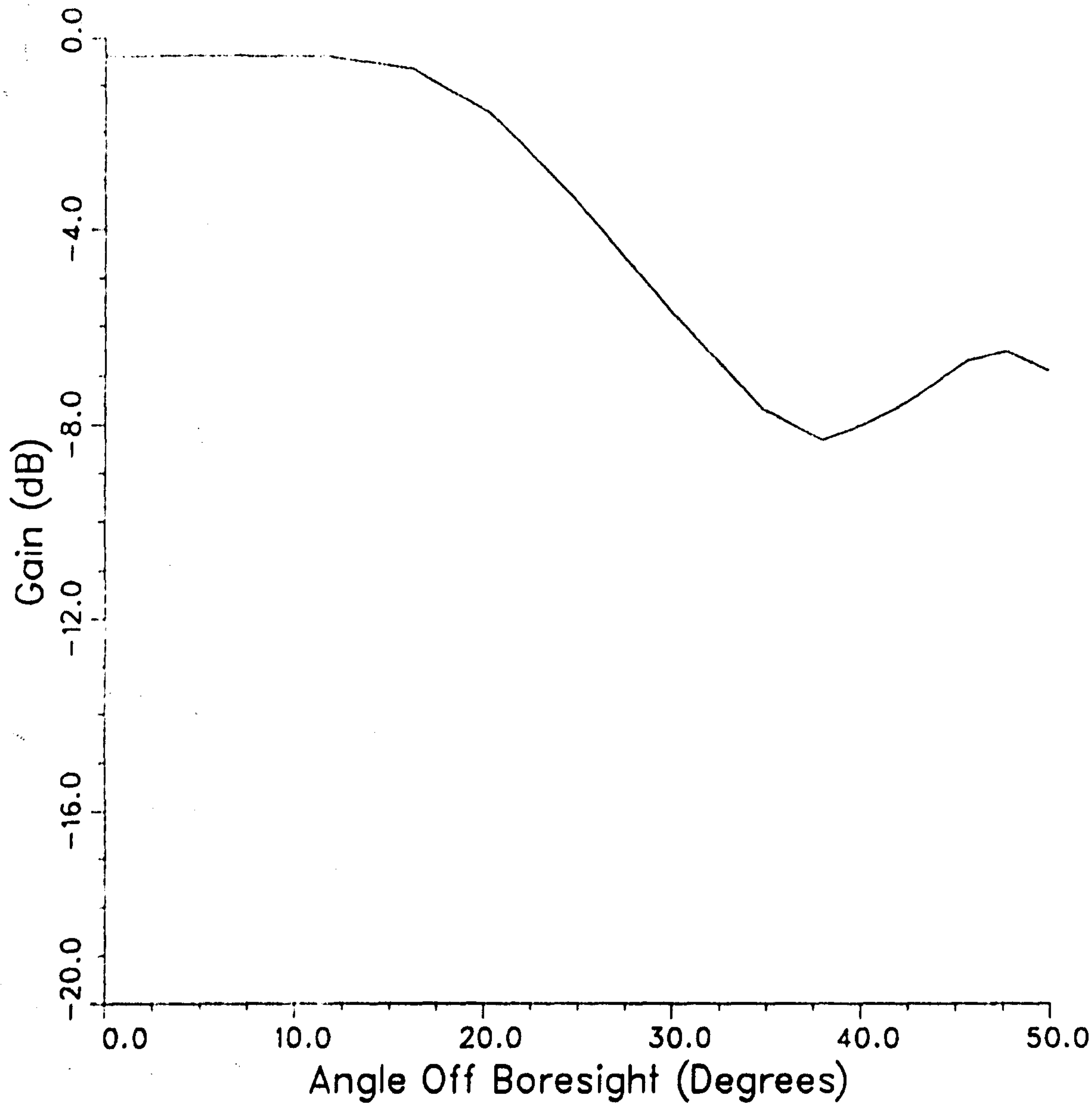
2-Way Antenna Elevation Pattern

X-Band VV

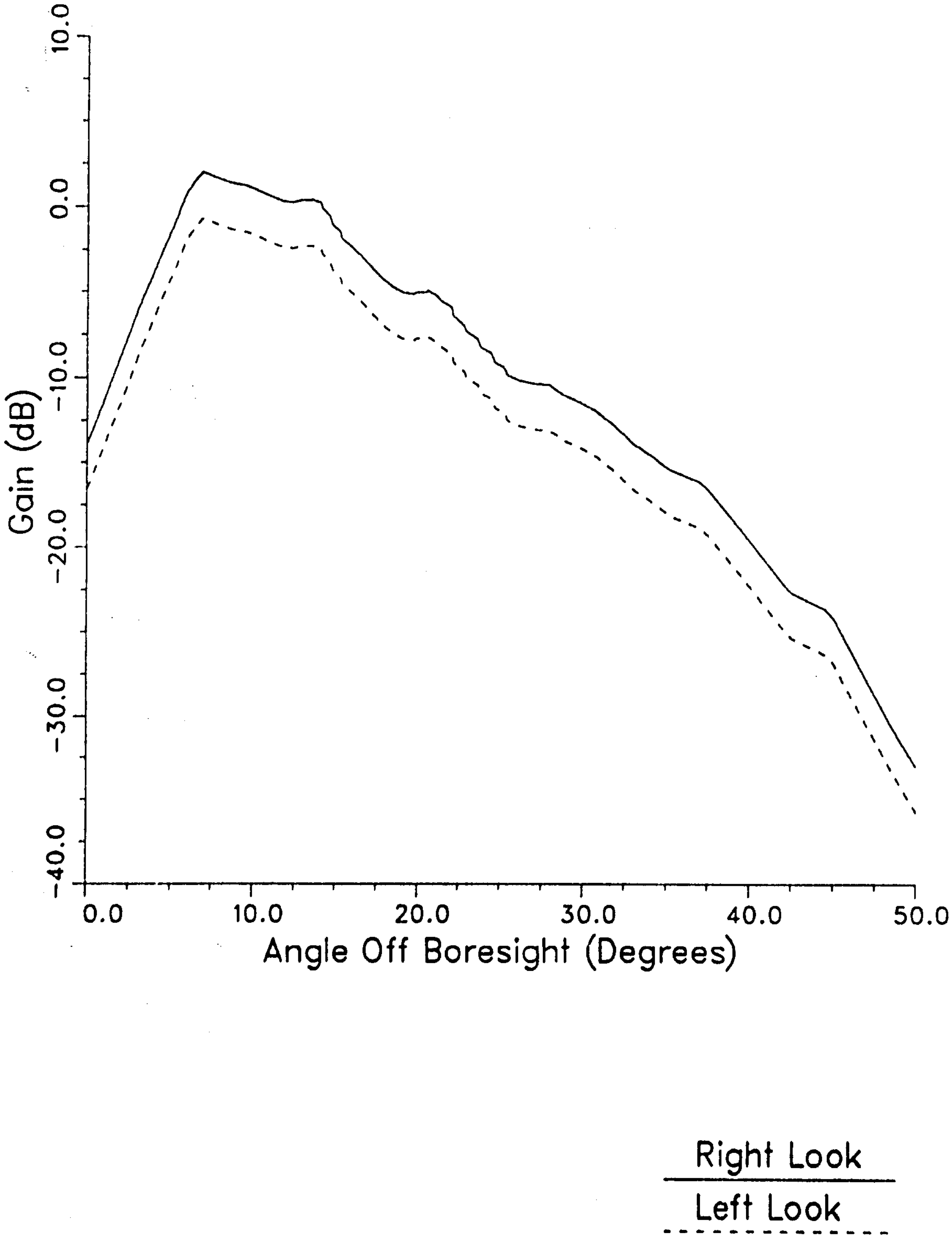


2-Way Antenna Elevation Pattern

L-Band VV



2-Way Antenna Elevation Pattern
C-Band VV



2-Way Antenna Elevation Pattern

L-Band HH